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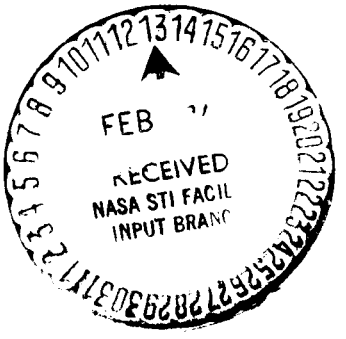
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

APOLLO 4 MISSION REPORT
SUPPLEMENT 7

COMMAND-MODULE/SERVICE-MODULE SEPARATION DISTURBANCES



MANNED SPACECRAFT CENTER
HOUSTON, TEXAS
May 1968

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COMMAND-MODULE/SERVICE-MODULE SEPARATION DISTURBANCES

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SUMMARY

A more detailed evaluation has been performed on the command-module/service-module (CM/SM) separation disturbances discussed in section 5.15.2 of the Apollo 4 Mission Report. Preliminary evaluation of the pitch-down, yaw-left rate transients of 4.5 deg/sec and 0.4 deg/sec during separation revealed that an external force was exerted upon the CM after the separation impulse had ended. The force continued for approximately 8 seconds and appeared first in the yaw axis and then transferred to the pitch axis.

This force was of a magnitude and in a direction that could be expected from the four SM reaction control subsystem (RCS) minus X engine plumes impinging upon the CM heat shield. Impingement effects (though small) were observed until the two vehicles were separated by 35 feet. Attitude excursions during this period can be on the order of 5 to 10 degrees if the separation is made in a manual control mode and rates are not corrected.

The cause of the transients and the rate and attitude disturbances appeared to be threefold: (1) energy stored in the CM/SM separation hardware (three tension ties and the umbilical guillotine), (2) delay in the CM-RCS responding to an engine firing command (this could be expected since the RCS had just been pressurized, but the lines not filled with propellants), and (3) impingement of the SM-RCS minus X engine plumes upon the CM heat shield as the SM yawed and pitched due to the offset in the center of gravity while the vehicle backed away and started the programmed roll maneuver.

No spacecraft changes are required but the flight crews will be made aware that rate and attitude excursions of the magnitude mentioned probably will occur.

Figure 1 is a time history of CM pitch and yaw rates and RCS engine firings. Table I is a summary of mass properties data during the time period of figure 1. The impulse to the CM can be seen during the first 0.3 second. The pitch-down, yaw-left disturbance was caused by the energy stored in the three tension ties and the umbilical guillotine.

The exact magnitude of rate changes that can be expected due to the tension ties and guillotine is not known; however, magnitudes experienced on AS-201, AS-202, and Apollo 4 mission, and from simulations and dynamic analyses at the contractor's facility all showed close agreement.

At 0.3 second, the effects of the impulse had dissipated and the pitch-up engines had been commanded on. The rates, however, did not

start to decrease until 0.5 second and pitch acceleration was not nominal until 0.7 second. This was attributed to (1) the RCS being pressurized for less than 2 seconds, (2) air in the fuel lines and improper mixture ratio, and (3) RCS pressures not having stabilized. These three effects have been noted in contractor simulations[a], which showed that full thrust may not be achieved until 0.5 second after a command to fire is received at the solenoid.

The yaw-left rate disturbances during the first 2 seconds are attributed to crosscoupling from the pitch-up engines and not to impingement forces because separation distances were still small and very little surface area of the heat shield was exposed.

At 2 seconds, the separation distance was approximately 5 feet; the SM was pitched down 3.5 degrees and yawed left 3.1 degrees and the CM was pitched down approximately 4 degrees. The SM body rates were caused by the four -X translation engines and center-of-gravity offsets of 13.8 inches and minus 14.6 inches in Y-axis and Z-axis, respectively. Thus, after the roll program started, the SM was accelerating at -0.6 ft/sec^2 in X_{SM}, minus 1.8 deg/sec^2 in yaw, and plus 13 deg/sec^2 in roll (all values calculated using nominal thrust and mass properties data derived from flight data). The relative motion between the SM and CM caused the top forward firing engine (engine 3, quad A, plus-pitch/minus-X) and right forward firing engine (engine 7, quad B, plus-yaw/minus-X) to impinge upon the CM heat shield.

Plume force studies showed that pitch and yaw disturbances of the magnitude and direction seen on the Apollo 4 SM after separation could cause CM pitch and yaw accelerations of 1.3 deg/sec^2 at a separation distance of 5 feet (10 feet from the SM-RCS engines) and translational accelerations of 3.2 ft/sec^2. Flight data indicated CM accelerations of 0.0 deg/sec^2 in pitch, minus 1.1 deg/sec^2 in yaw, and translational accelerations of plus 0.28 ft/sec^2 at a separation distance of 5 feet. The pitch acceleration was zero at 5 feet because the relative position of the two vehicles at that time caused cancelling torques on the CM; however, as the SM rolled, the pitch torque disturbances became apparent but of lesser magnitude because of the greater separation distance.

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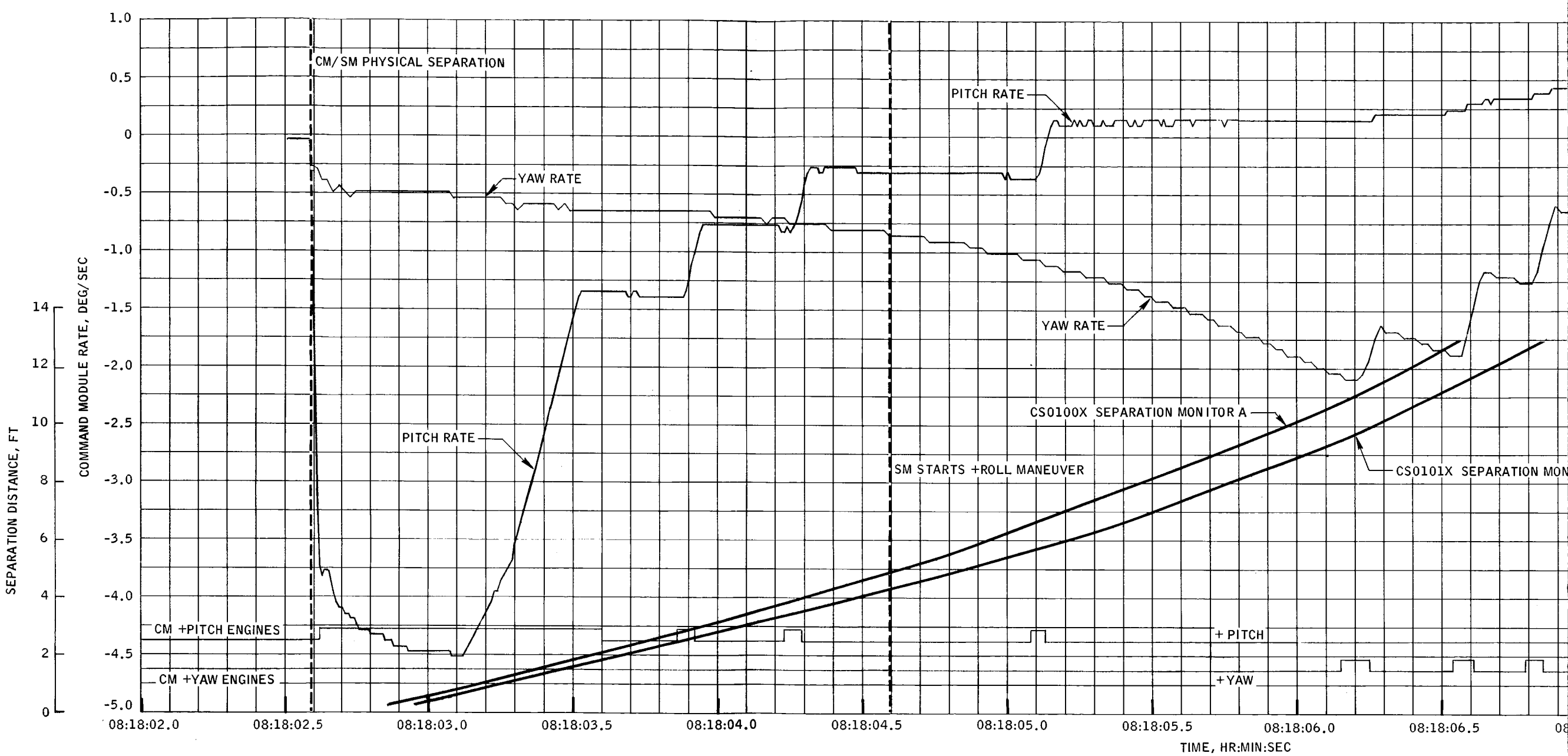
[a]North American Rockwell Corporation Report: SID-67-341 "Apollo CM RCS Block II Certification Test Final Report."

TABLE I.- APOLLO 4 MASS PROPERTIES AT CM/SM SEPARATION

	Weight, lb	Center of gravity, in.			Moment of inertia, slug-ft^2		
		X	Y	Z	I_{xx}	I_{yy}	I_{zz}
CSM (Just prior to separation)	31 227.6	947.4	8.6	-6.5	17 300	56 250	56 200
CM (Just after separation)	11 958.9	1 039.53	0.3	6.57	6 017	5 515	4 673
SM (Just after separation)	19 268.7	890.2	13.8	-14.6	10 277	14 533	15 755


CM/SM PHYSICAL SEPARATION
PITCH RATE
YAW RATE
YAW RATE
PITCH RATE
CS0100X SEPARATION MONITOR A
SM STARTS +ROLL MANEUVER
CS0101X SEPARATION MON
CM +PITCH ENGINES
CM +YAW ENGINES
+ PITCH
+YAW
SEPARATION DISTANCE, FT
COMMAND MODULE RATE, DEG/SEC
TIME, HR:MIN:SEC
1.0
0.5
0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
-3.5
-4.0
-4.5
-5.0
14
12
10
8
6
4
2
0
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FOLD-OUT #1

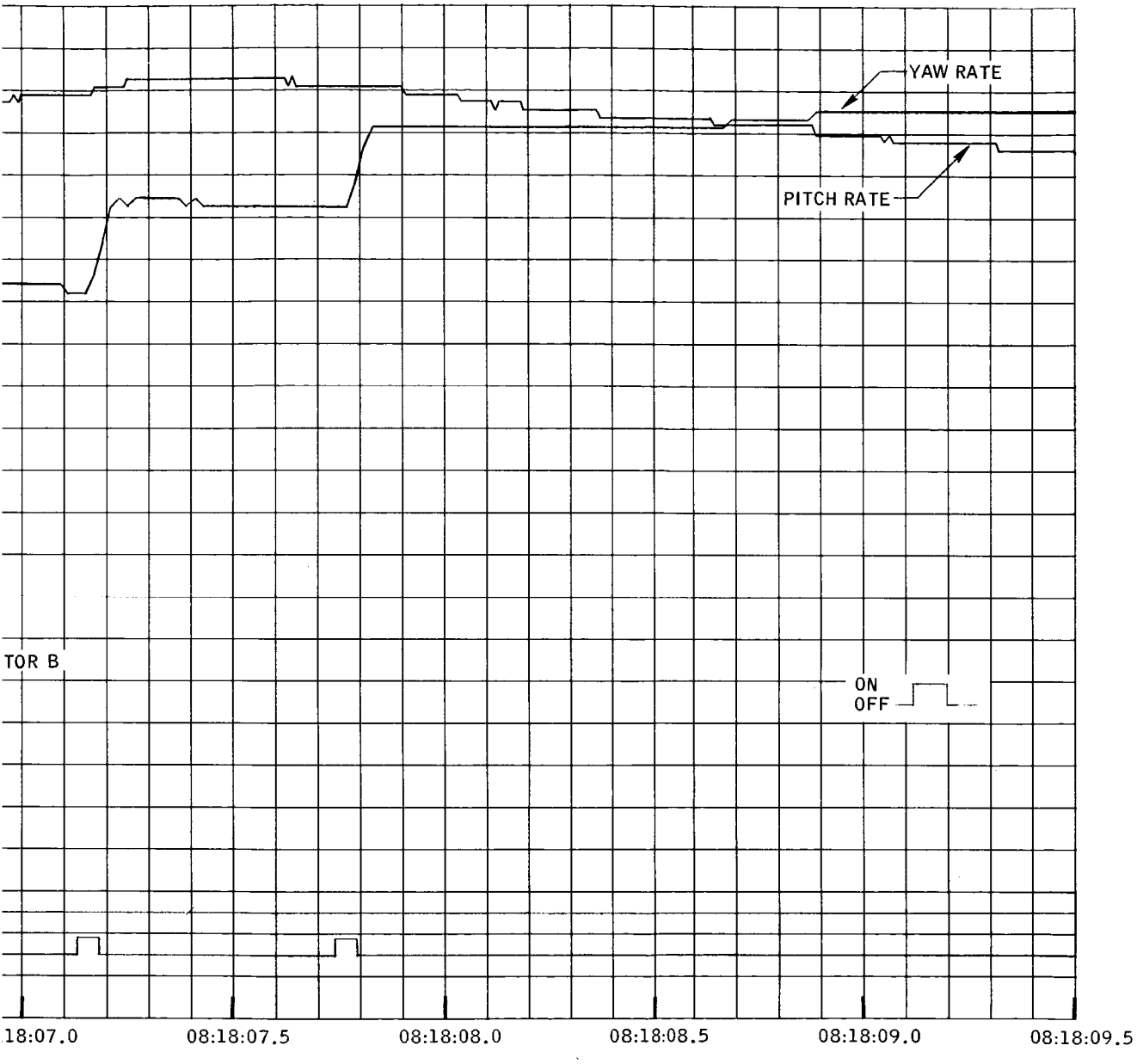

FIGURE 1.- COMMAND MODULE DYNAMICS DURING COMMAND MODULE/SERVICE MODULE SEPARATION.

FOLD-OUT #2